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Integrating spatial data and nesting locations to predict the future impact of global warming on coastal habitats: A case study of shorebirds in Farasan Islands, Saudi Arabia

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Abstract

One of the expected effects of the global warming is changing coastal habitats by accelerating the rate of sea level rise. Coastal habitats support large number of marine and wetland species including shorebirds (plovers, sandpipers and allies). In this study, we investigate how coastal habitats may be impacted by sea level rise in the Farasan Islands, Kingdom of Saudi Arabia. We use Kentish plover *Charadrius alexandrinus* – a common coastal breeding shorebird – as an ecological model species to predict the influence of sea level rise. We found that any rise of sea level likely to inundate 11% of Kentish plover nests. In addition, 5% of the coastal areas of Farasan Islands, which supports 26% of Kentish plover nests, will be flooded, if sea level rises by one metre. Our results are constrained by the availability of data on both elevation and bird populations. Therefore, we recommend follow-up studies to model the impacts of sea level rise using different elevation scenarios, and the establishment of a monitoring programme for breeding shorebirds and seabirds in Farasan Islands to assess the impact of climate change on their populations.

1. Introduction

During the 21st century, climate change will be one of the major impacts of humans on natural ecosystems (Dawson et al., 2011). Although the magnitude, spatial distribution and impacts of climate change are still being quantified, climatologists agree that one of the major impacts will be sea level rise due to melting of currently frozen water mainly in the Antarctic and the Arctic regions (Meehl et al., 2005). Sea level rise due to climate changes predicted to be between 0.18m and 1.2m by 2100 (IPCC, 2007; Rahmstorf et al., 2007). This will potentially pose a major threat to coastal areas, disrupt coastal ecosystems, and induce changes in breeding and feeding areas of shoreline dependent organisms including shorebirds that feed and breed on coastal and intertidal habitats (Hughes, 2004; Baker et al., 2006; Finlayson et al., 2006; Fujii and Raffaelli, 2008; Nicholls et al., 2009; Chu-Agor et al., 2011).

Here we investigate an aspect of the potential future impact of sea live rise on coastal-breeding shorebirds using Kentish plover *Charadrius alexandrinus* as an ecological model species (AlRashidi et al., 2011a). Shorebirds (sandpipers, plovers, gulls and allies; about 350 species) are an excellent group to investigate the coastal impacts of climate change (Piersma and Lindstrom, 2004). They are distributed globally (Monroe and Sibley, 1993; del Hoyo et al., 1996), and they indicate global environmental changes such as ecosystem health and climate change (Piersma and Lindstrom, 2004; Thomas et al., 2006). In addition, they exhibit exceptional diversity in their life history and behaviour including breeding systems, foraging behaviour and migratory habits (Székely et al., 2006; Thomas et al., 2006; García-Peña et al., 2009).

Here we focus on the Farasan Islands, an archipelago in the Red Sea about 50 km from the city of Jizan, Kingdom of Saudi Arabia. It was established as a protected area in 1996 by the Saudi Wildlife Commission (SWC). It is one of the most important breeding sites for seabirds and shorebirds in the Red Sea including the endemic White-eyed gulls *Larus leucophthalmus* and Crab plover *Dromas ardeola* (PERSGA/GEF, 2003). These islands comprise a variety of habitat types including mangrove, wet and dry salt marshes, sand dunes, sand plains and rocky habitats (El- Demerdash, 1996).

2. Methods

2.1. Fieldwork and breeding data collection

Fieldwork was carried out in three years (between 8^{th} and 19^{th} of July in 2007, between 17^{th} of April and 4^{th} of July in 2008, and between the 15^{th} of May and 4^{th} of July in 2009) in the Farasan Islands. The Kentish plover is a common shorebird on the Farasan Islands, nesting on salt marshes and sand dunes up to 1 km away from the shore. We used a four-wheel-drive car to search for nests, and once a nest was found, its location was recorded using a hand held GPS unit (Garmin e-Trex, see details in AlRashidi et al., 2011a&b).

2.2. Topographic analysis

A digital elevation model (DEM) data acquired from the Shuttle Radar Topography Mission (SRTM) onboard the Space Shuttle Endeavor (launched in December 2000) were downloaded from the Global Landcover Facility (*http://www.landcover.org*), and were used to investigate the topographic variations of the study area. This seamless DEM image has 90 m spatial resolution and 1m vertical resolution, and uses a Universal Transverse Mercator (UTM) projection (Zone 38). Arc-Map Software was used to classify elevation of the studied islands on the bases of 1m elevation interval. The number of pixels representing the elevation of 0-1m height was counted to assess potential areas of inundation by a rising sea level, assuming 1m increase in mean high tide values.

3. Results and discussion

23 out of 207 Kentish plover were located at/or below sea level; therefore any rise of sea level predicted to inundate 11% of these nests (Table 1). In addition, Farasan Islands is estimated around 700 km^2 and the total coastal area that located below 1m and is subjected to the possibility of inundation if the sea level rise by one metre is 35 km^2, which is approximately 5% of the islands' area (Fig 1). The 35 km^2 area holds 26% of Kentish plover nests, i.e. 54 out of 207 nests (Fig 2).

Sea level rise due to thermal expansion and the melting of land based ice is likely to have a major impact on island coastal and intertidal habitats, leading to increase their loss and erosion, with the heaviest impact predicted for salt marshes and sandy beaches (Böhning-Gaese and Lemoine, 2004; Hughes, 2004; Baker et al., 2006; BirdLife International, 2008). Our results reflect concerns raised by the study of Austin and Rehfisch (2003) that suggests sea level rise will affect both the extent and quality of coastal habitats in the UK. Galbraith et al. (2002) modelled the potential impacts of sea level rise and climate change on shorebird tidal foraging habitat at five important migration sites in the US, and reported major intertidal habitat losses at four of the sites. In addition, Le V. dit Durell et al. (2006) found that a reduction of just 10cm of intertidal habitats in Poole Harbour, UK removed sufficient area in the harbour to reduce survival rates in all shorebird species. A reduction of 40 cm meant that no birds at all survived the winter.

Our results are in line with the recent study on closely related species, Aiello-Lammens et al. (2011) assessed the effect of sea level rise on the viability of the Snowy plover population along the Gulf Coast in Florida, US. Their results indicated that sea level rise will cause a decline in suitable habitat and carrying capacity for Snowy plover leading to an increase in the risk of its extinction and decline.

Global warming is already taking place, and a recent work by Cantin et al. (2010) found strong evidence in Red Sea region. Cantin et al. (2010) found that the summer sea surface temperatures of the Red Sea over the last 10 years have been on average 1.46˚C higher than the historical mean of temperatures from 1950-1997, and the increased sea temperature has lead to reduced coral growth.

The major objective of our study is to undertake some preliminary work to highlight two important issues. First, there are coastal areas in the Farasan Islands where sea level rise could result in the loss of ecologically important habitats. Second, our work highlights a considerable need for ongoing research and monitoring shorebirds and other animals at the study site, and indeed in the whole Red Sea region. Future works should expand the scope of our study at least in three respects.

First, we assumed that birds will not adapt to climate change and continue breeding in the same location. This assumption is not entirely realistic, since birds should exhibit plasticity in nest site selection and where habitats allow, will shift nest locations to higher elevation sites especially when new habitat equilibrium is reach at a later stage after initial sea levels rise. However, shifting nesting territories may be problematic when other factors constrain it, such as the presence of hard sea defence which prevents landward migration of coastal habitats (Norris and Buisson, 1994; Sharpe and Huggett, 1998; Rehfisch and Austin, 2006), and the potential to induce density-dependence by crowding more plovers onto a smaller area (Smart and Gill, 2003; Kosztolányi et al., 2006). As nesting density increases, fights for territories will likely to intensify and this may lead to reduced breeding success (Kosztolányi et al., 2006). Further GIS-based studies would look at the topographical nature of the areas beyond the 1m band investigated in this work, to quantify the potential for habitat (and hence plover) re-distribution.

Second, our results were constrained by the availability of freely available elevation data. Consequently, we recommend a follow-up study that investigates the impact of sea level rise by modelling at least three scenarios (5cm, 25cm and 50cm) of sea level rise on Red Sea costal habitats which can be obtained from Airborne LiDAR.

Third, our study should be extended to include other shorebirds and seabirds that breed or forage on this region. On the one hand, breeding of endemic species may be influenced by sea level rise, eg White-eyed gull *Larus leucopthalmus* Sooty gull *Larus heimprichii*, White-cheked tern *Sterna repressa*. On the other hand, the availability of foraging habitats may change for a number of species including Lesser sand plover *Charadrius mongolus*, Greater sand plover *C. leschenaultii*, Little ringed plover *C. dubius* and Crab plover *Dromas ardeola*. Therefore, an integrative study is needed that will take into account the impacts on both foraging and breeding habitats.

4. Conclusions

Taken together, our study shows that coastal areas on Farasan Islands are vulnerable to the effects of climate change, especially to sea level rise. Our preliminary study suggests that a substantial percentage of suitable nest sites will potentially be lost for a species that breeds close to the coast. Future studies are needed to relax the assumptions of our study by taking into account behavioural plasticity in nest site selection, and using a finer elevation scale for modelling sea level rise. Finally, our study points out the urgent need to monitoring seabirds and shorebirds in the Farasan Islands, and integrate these monitoring data with remote-sensing and climate change models.

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Table 1. Number of Kentish plover nests and their percentage in relation to elevation data.

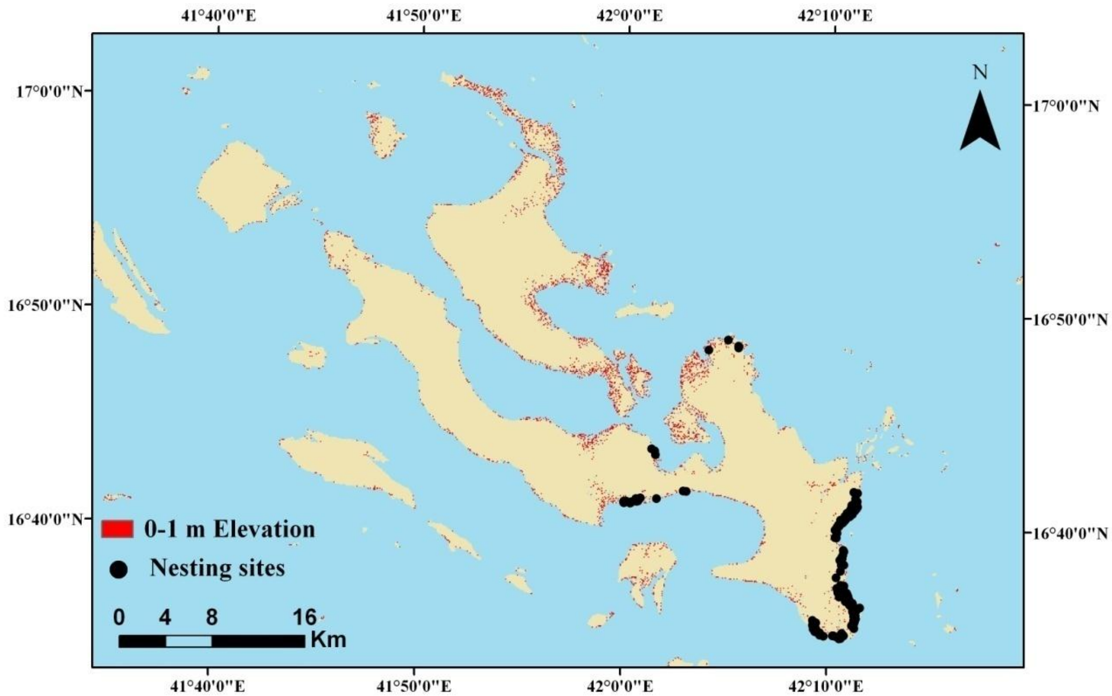
Elevation	**Nest numbers (%)**
More than 1 metre	153 (73.91)
More than zero and less than or equal to 1 metre	31 (14.97)
Zero or less	23 (11.11)
Total	207 nests

Figure legends

Fig. 1. Map showing the coastal areas with elevation less than 1m (red colour areas), and all nests of Kentish plover included in the study (n = 207 nests, black dots).

Fig. 2. Map showing the coastal areas with elevation less than 1m (red colour areas), and Kentish plover nesting locations which will be flooded if the sea level rise by one metre (black dots).

Fig. 1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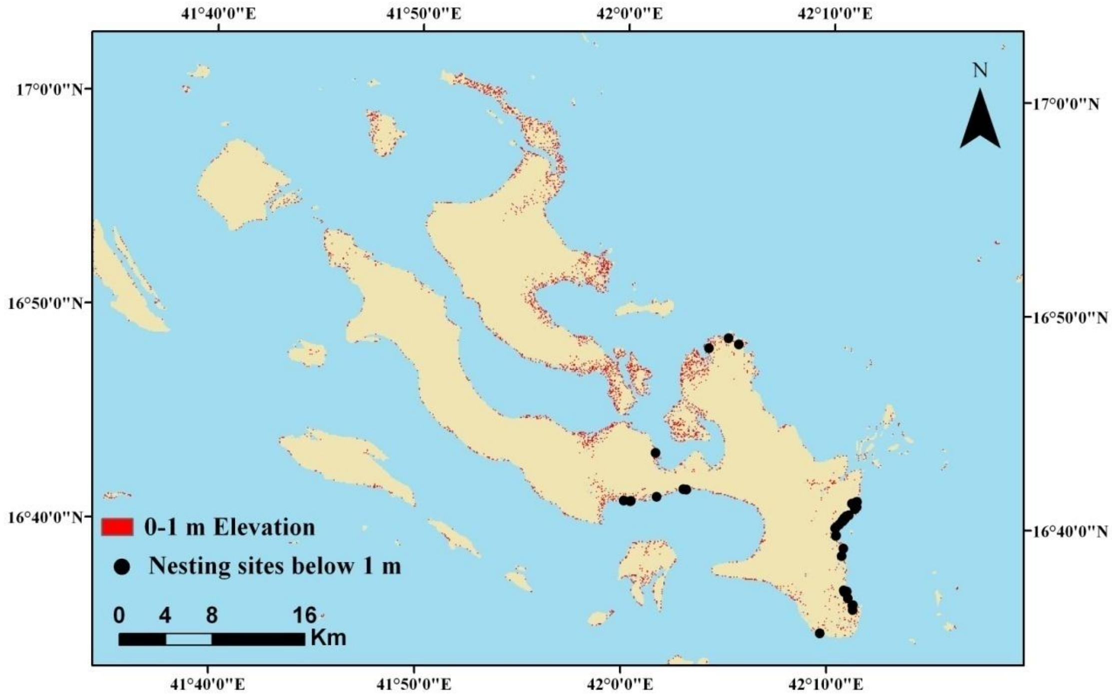
41°50'0"E
42°0'0"E
42°10'0"E
17°0'0"N
16°50'0"N
16°40'0"N
N
0-1 m Elevation
Nesting sites
0 4 8 16
Km

Fig. 2


41°40'0"E
41°50'0"E
42°0'0"E
42°10'0"E
17°0'0"N
16°50'0"N
16°40'0"N
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0-1 m Elevation
Nesting sites below 1 m
0 4 8 16
Km